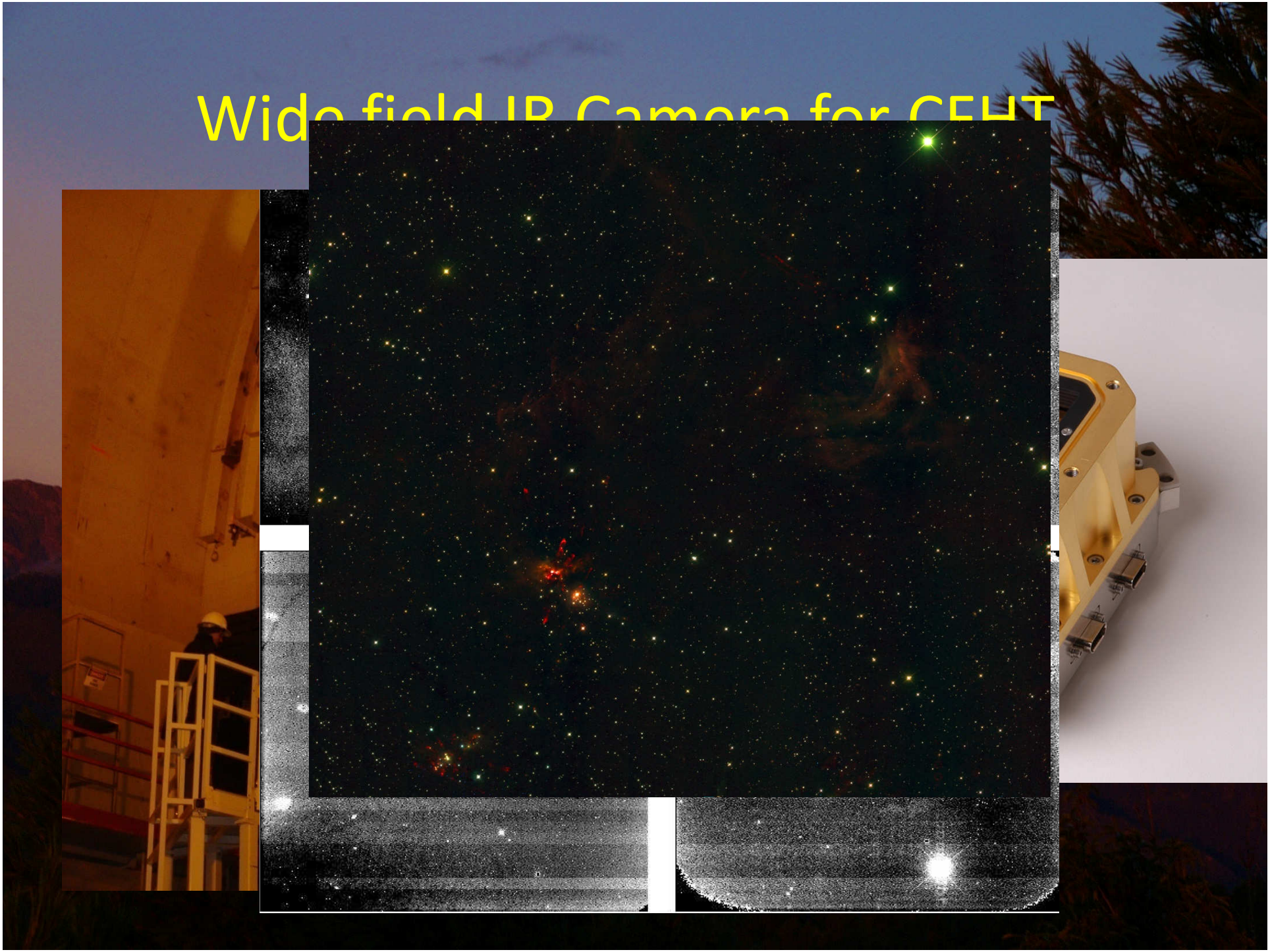
Detection Wavelength and Device Performance Tuning of InAs QDIPs with Thin AlGaAs Layers

Shiang-Yu Wang[a], Hong-Shi Ling[b], Min-Cheng Lo[b], Chien-Ping Lee[b]

[a]Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan

[b]Department of Electronic Engineering, National Chiao Tung Univ, Taiwan

Wide field IR Camera for CFHT



Detection Wavelength and Device Performance Tuning of InAs QDIPs with Thin AlGaAs Layers

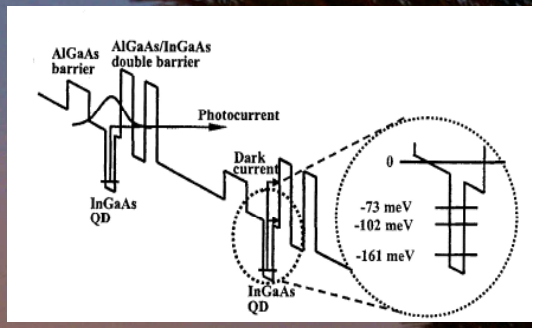
Shiang-Yu Wang[a], Hong-Shi Ling[b], Min-Cheng Lo[b], Chien-Ping Lee[b]

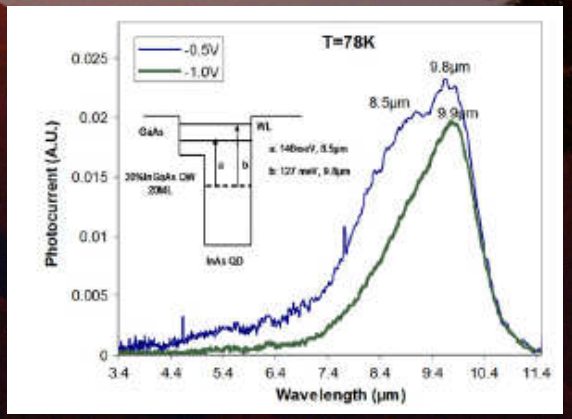
[a]Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan.

[b]Department of Electronic Engineering, National Chiao Tung Univ, Taiwan.

Progress of QDIPs

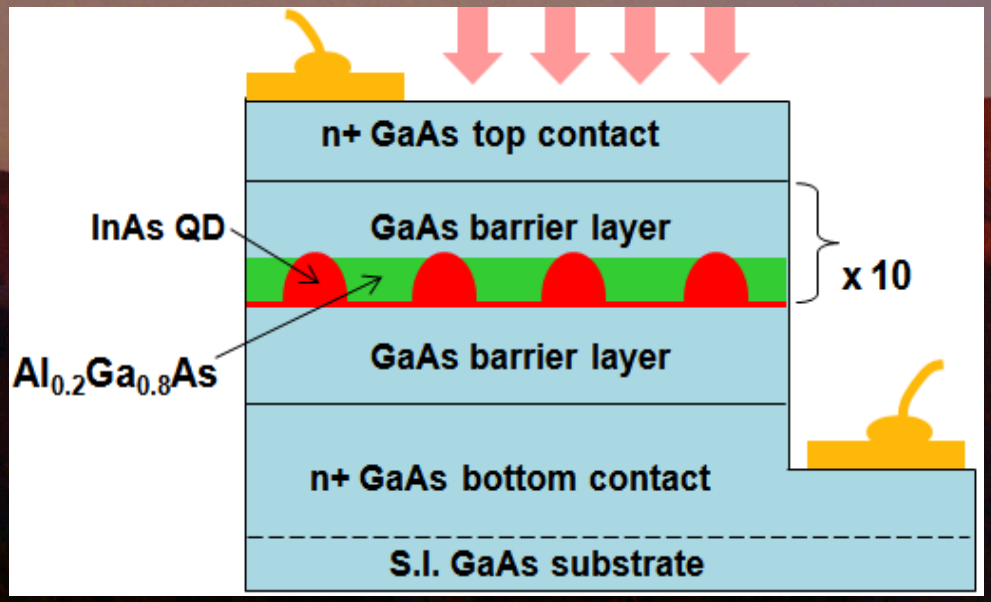
- High operating temperature demonstrated
  - In(Ga)As /GaAs with AlGaAs barriers
    - S. Chakrabarti, et.al. IEEE PTL, 16, 1361, 2004.
    - P. Bhattacharya, et. al. APL., 86, 191106, 2005.
  - InAs/InGaAs/GaAs DWELL
    - X. Lu, et.al. APL. 91, 051115, 2007.
    - H. Lim, et. al. APL. 90, 131112, 2007.
- QDIPs arrays:
  - 640x480 arrays demonstrated
    - DWELL QDIPs
    - Gunapala et. al. Infrared Phys. & Tech 50, 149, 2007

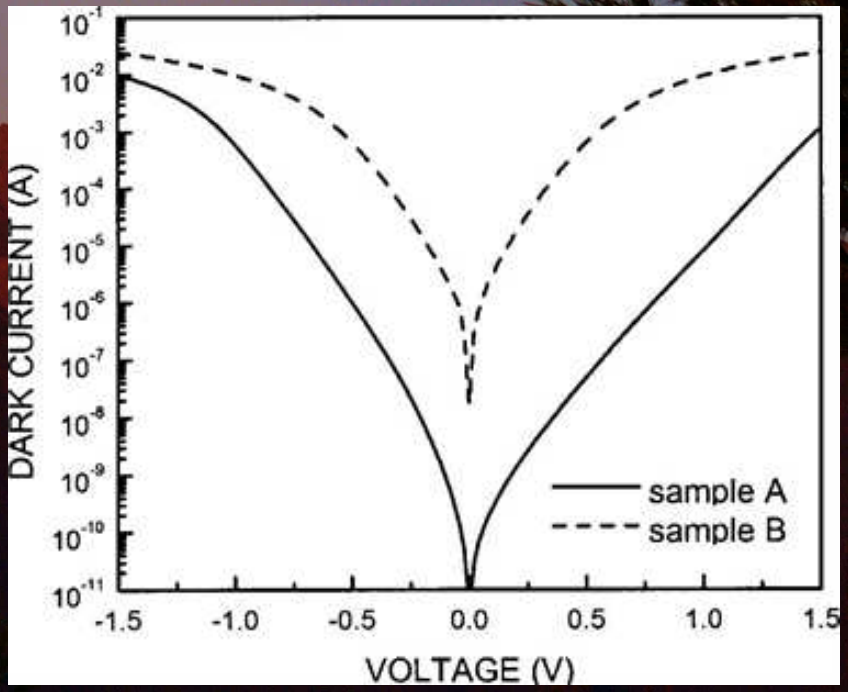




Thin AlGaAs layers

- The dark current is greatly reduced with 25 Å AlGaAs layer
- no obvious peak wavelength shift

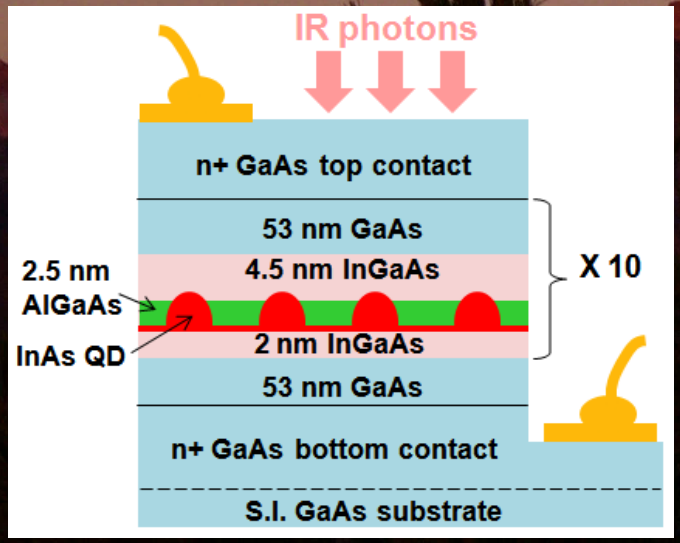


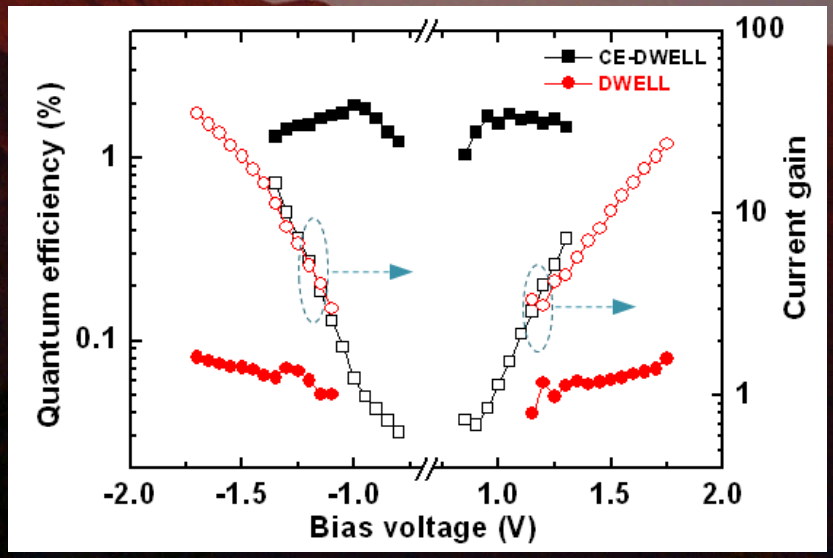


Details in S. Y. Wang et.al APL 78, 1023, 2001

Thin AlGaAs layers

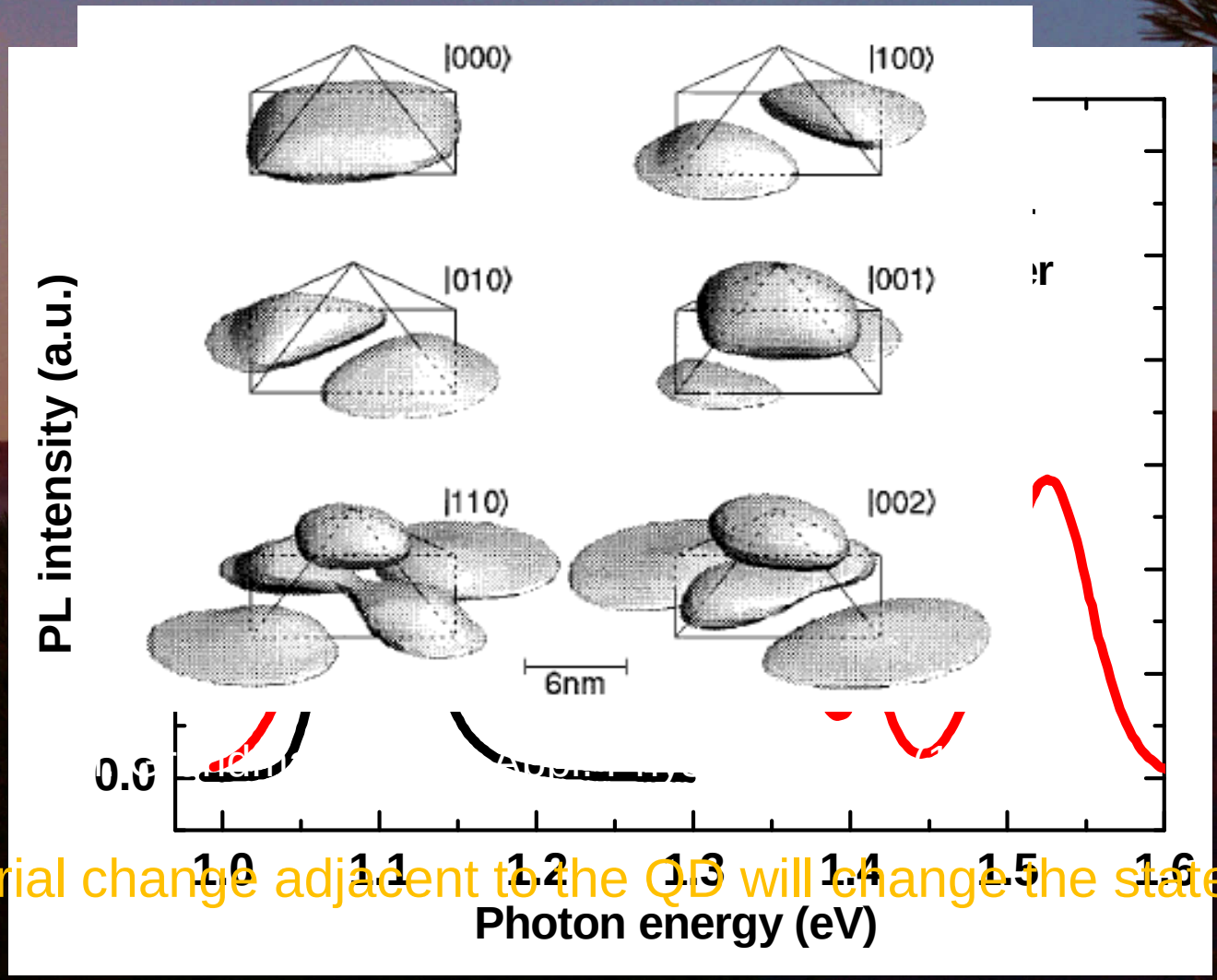
- The QE is enhanced by 10 times with an additional thin AlGaAs layer on QDs in DWELL structure
- D* at 77K is 3.5 x 10^{10} cm $Hz^{0.5}$ / W (@ -0.9V, 8μm)





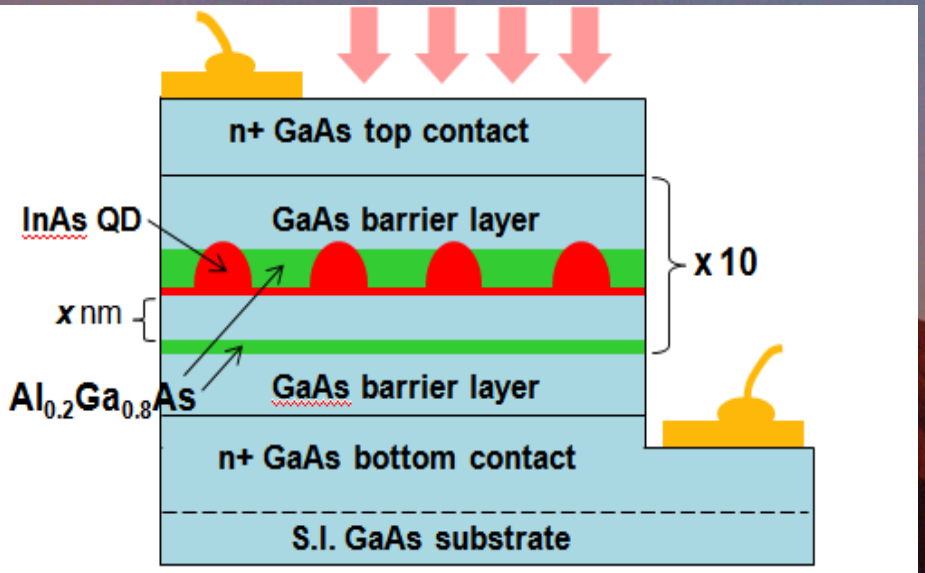
Details in Ling et.al APL 92, 193506, 2008 and talk in this conference

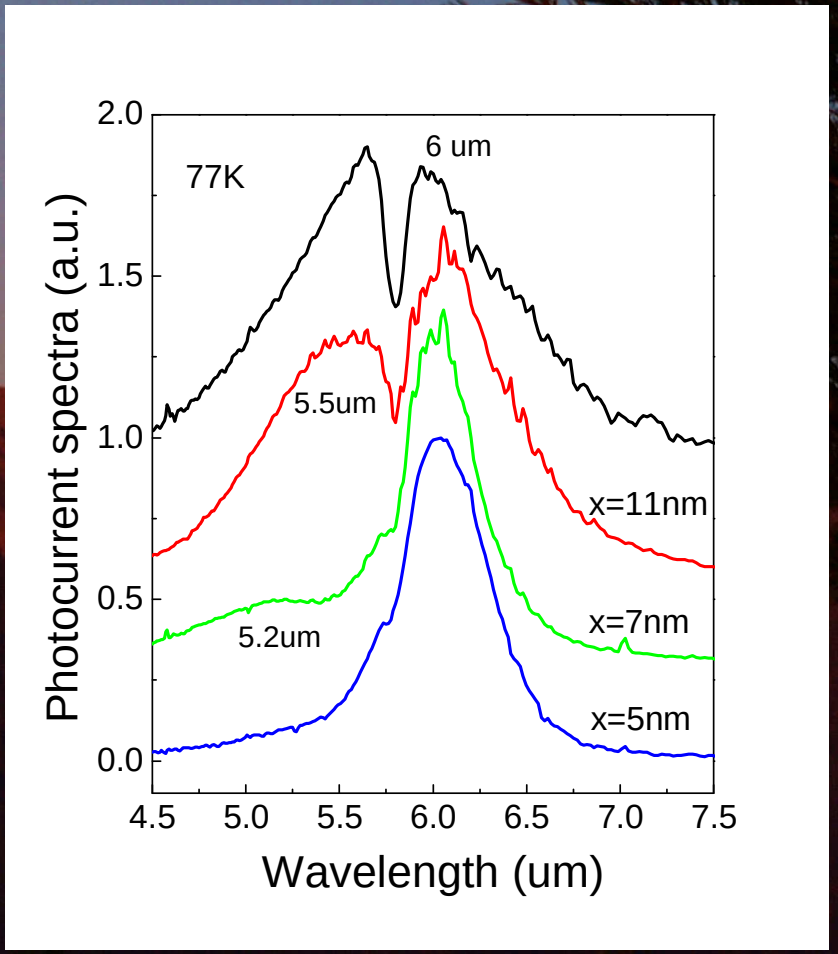
QD states



material change adjacent to the QD will change the states easily

InAs/GaAs QDIP with thin AlGaAs



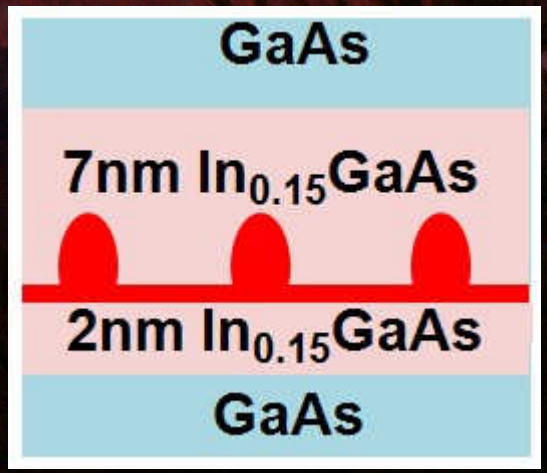


- 4 samples
- X= 5, 7, 11 nm & control sample

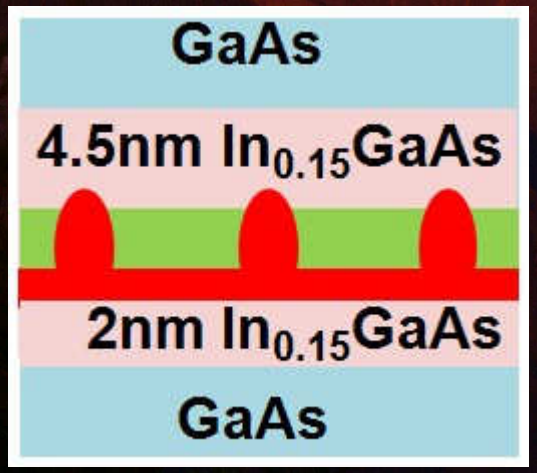
D* ~ 4.1×10^{10} cmHz$^{0.5}$/W @77K

DWELL QDIP with thin AlGaAs

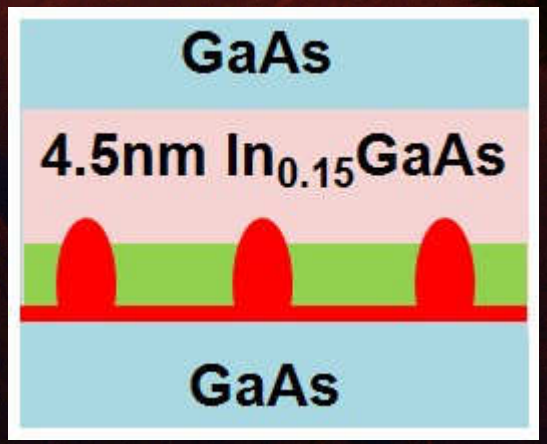
- QDIPs with 10 layers of different QD structures are compared
- All QD are of the similar sizes and density
- All QDs are modulation doped to around $1e^-$/QD
- 2.5 nm $Al_{0.3}Ga_{0.7}As$ layers were used



sample A

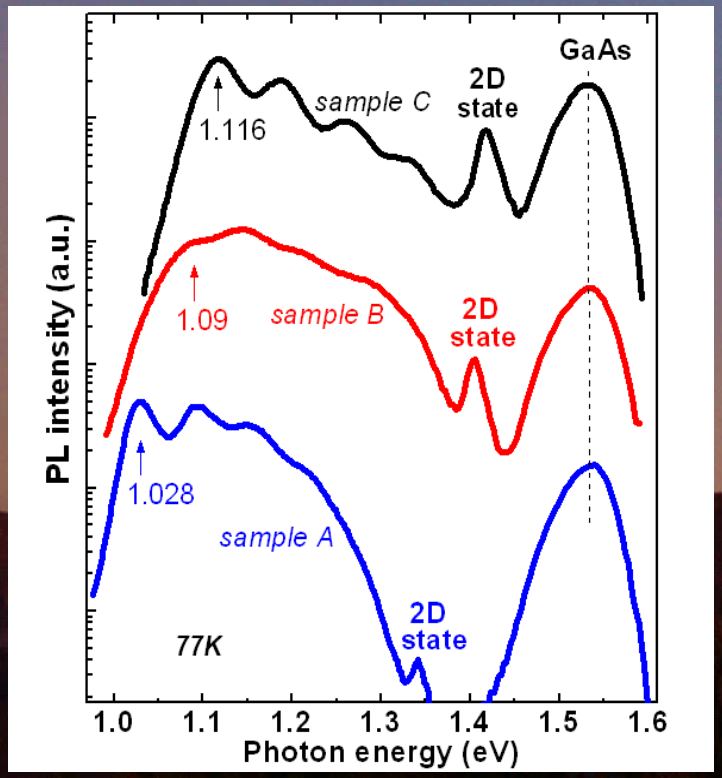


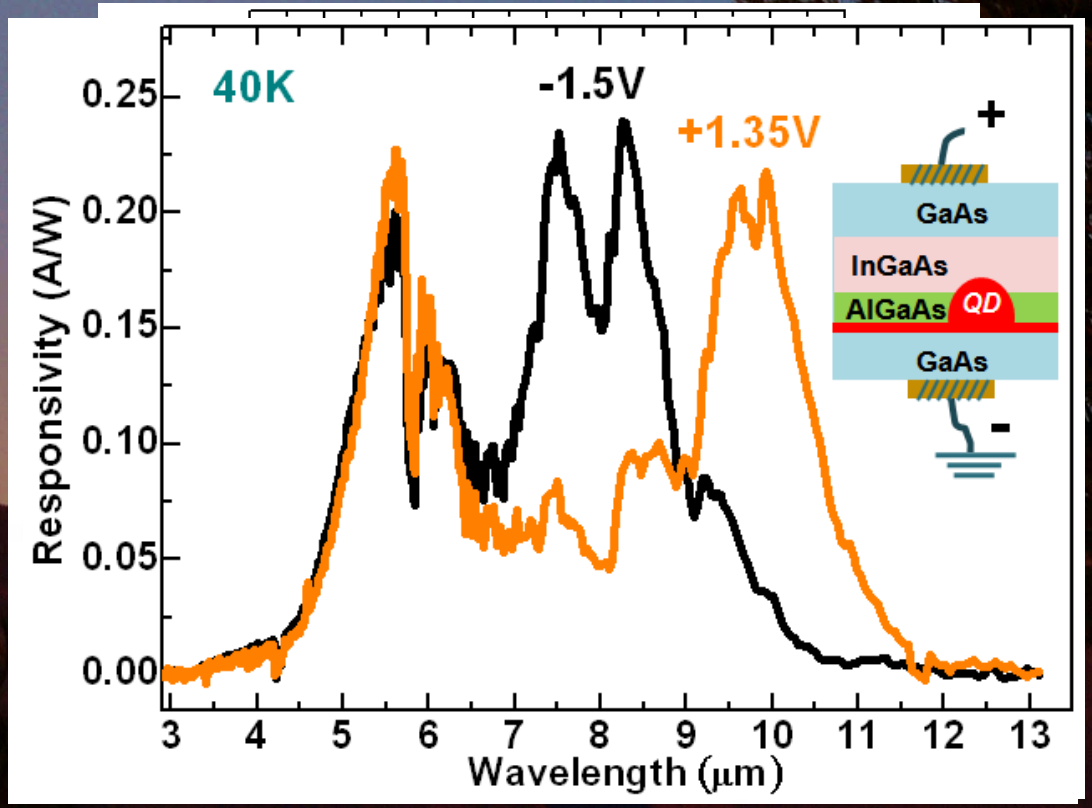
sample B



sample C

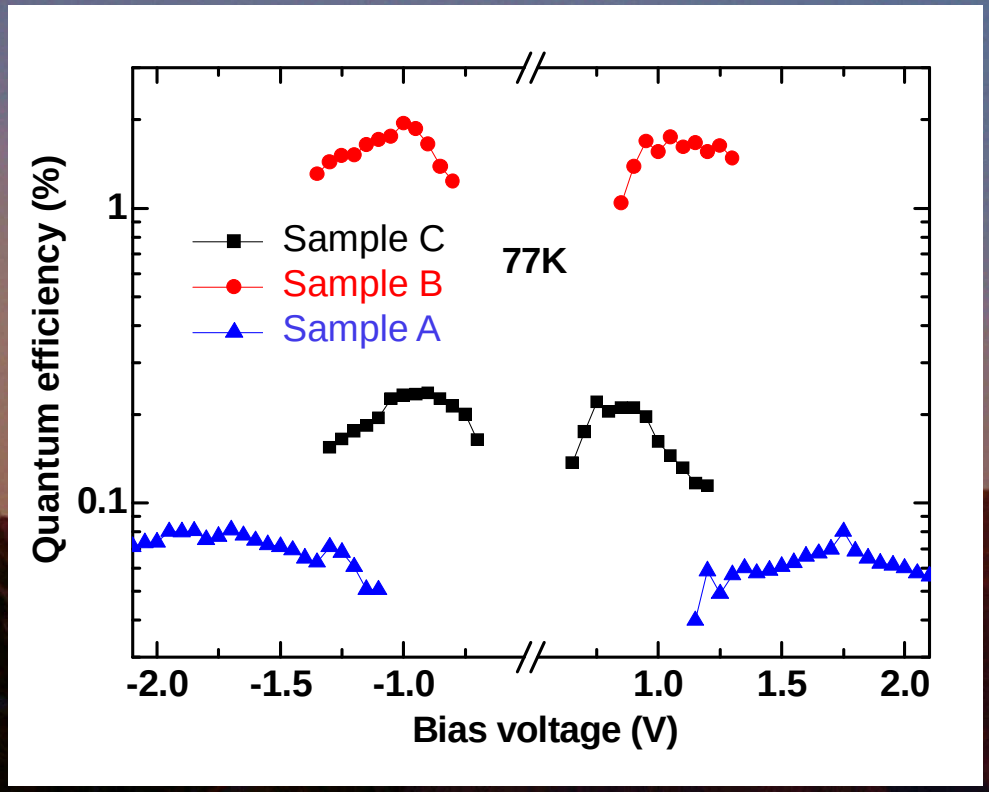
QD states





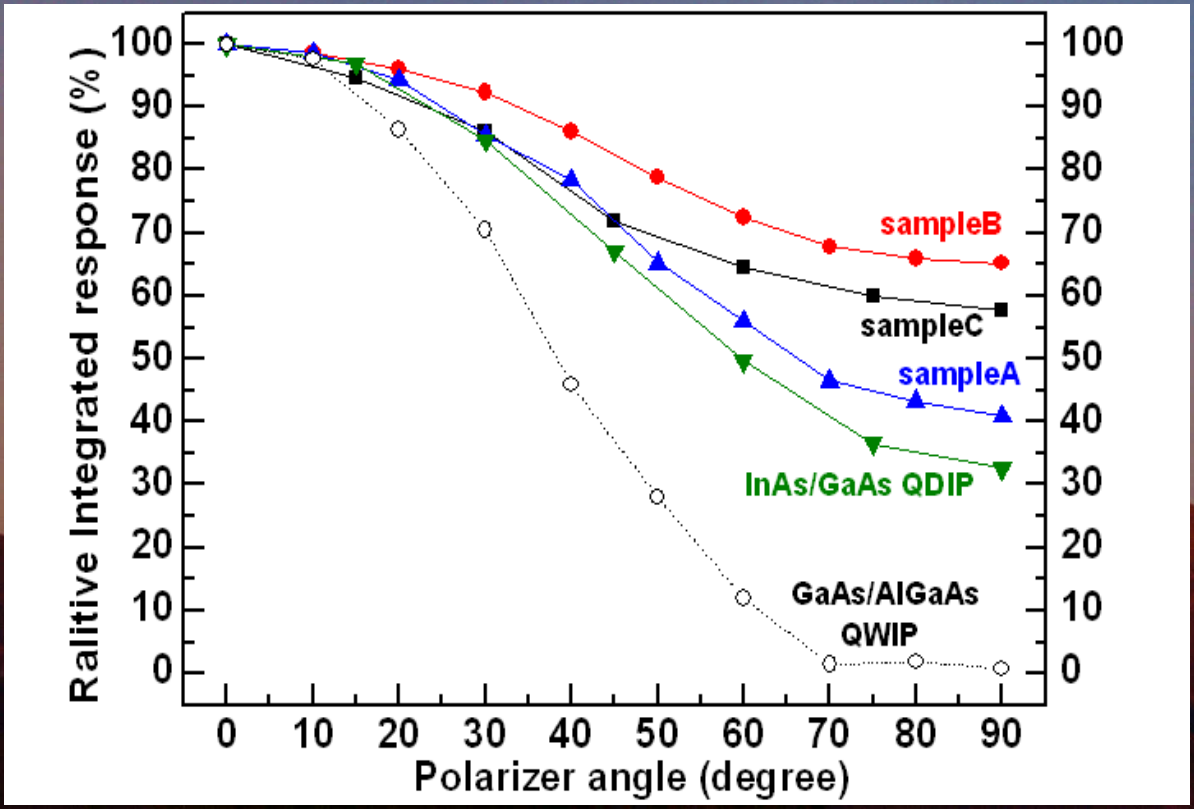
- Ground state energy increases with the confinement effect
- Separation of state energy (detection wavelength) increases with the confinement

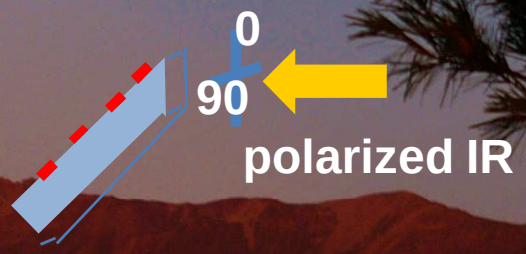
QE with normal incident light



- The better confinement enhances the QE
- The higher excited state energy also improves
  - ΔE_{exc} ~ 80 meV

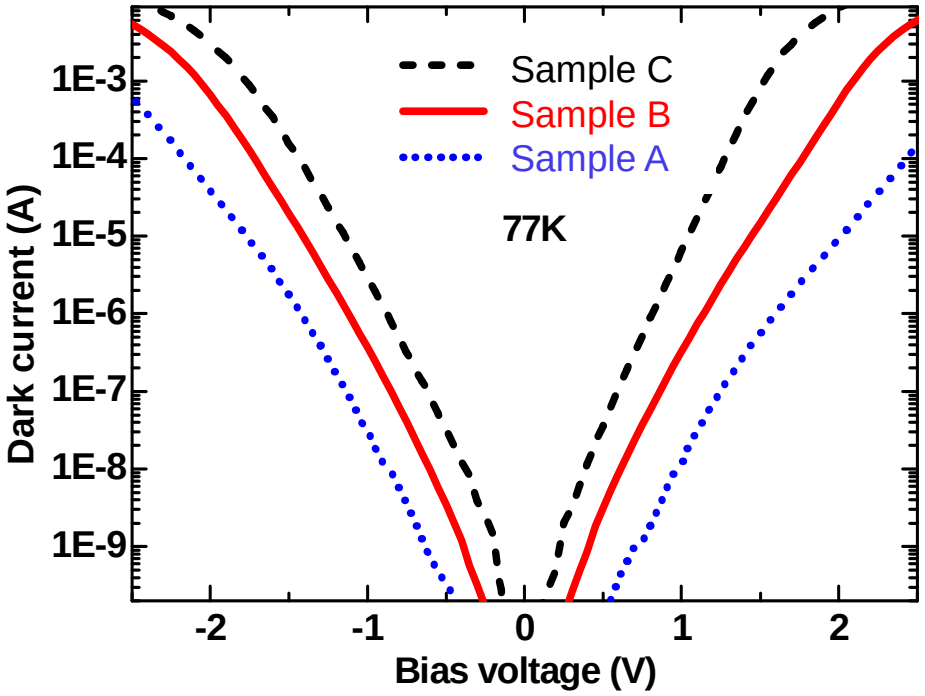
Polarization v.s. response

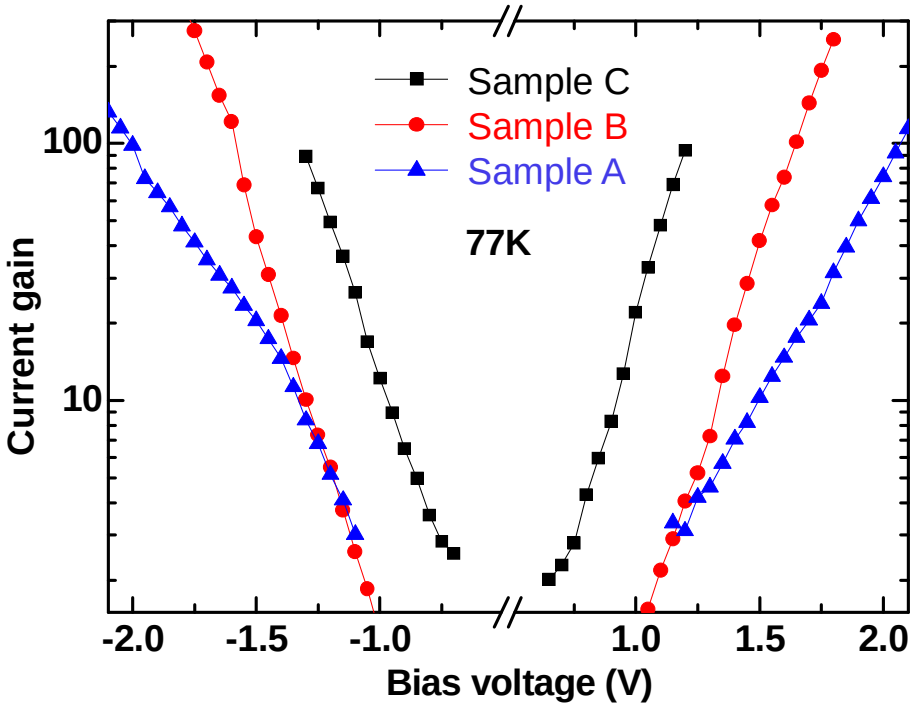




- The polarization response depends on both in plane and z direction confinement
- Transition to QD states also helps the TE absorption

Transport properties

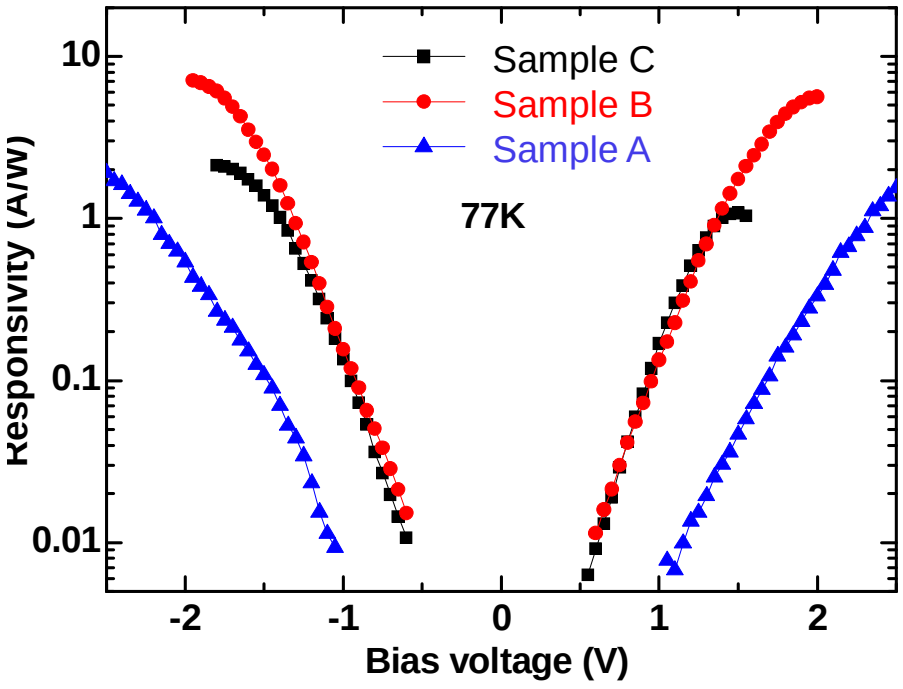


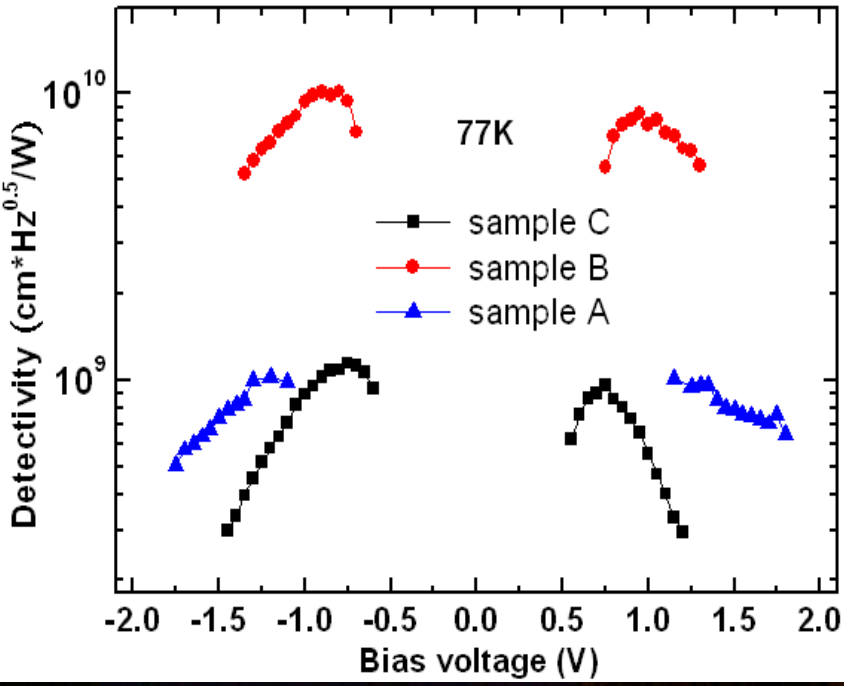


- Increase of dark current << exp(60meV/kT)
- The reduction of the InGaAs thickness increase the gain

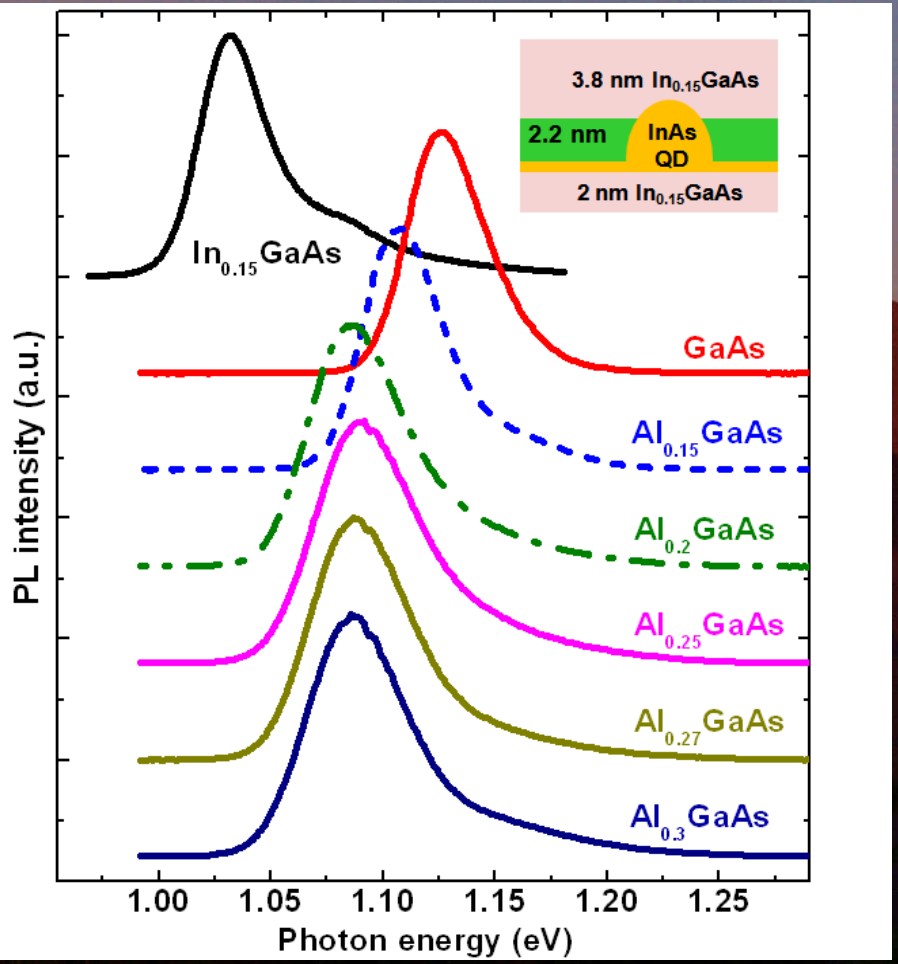
Overall performance

- The device with higher excited state operate at lower bias
- The devices with AlGaAs layer show higher D*



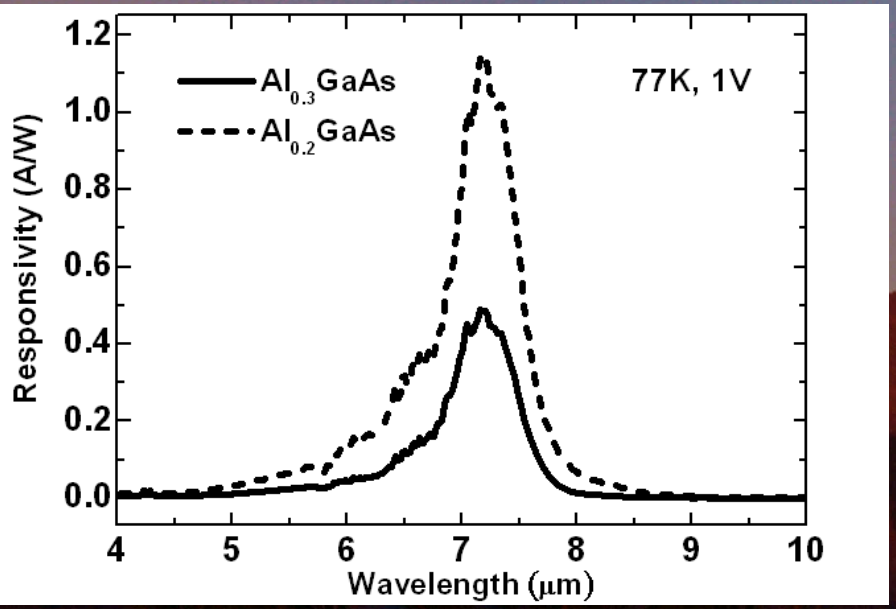


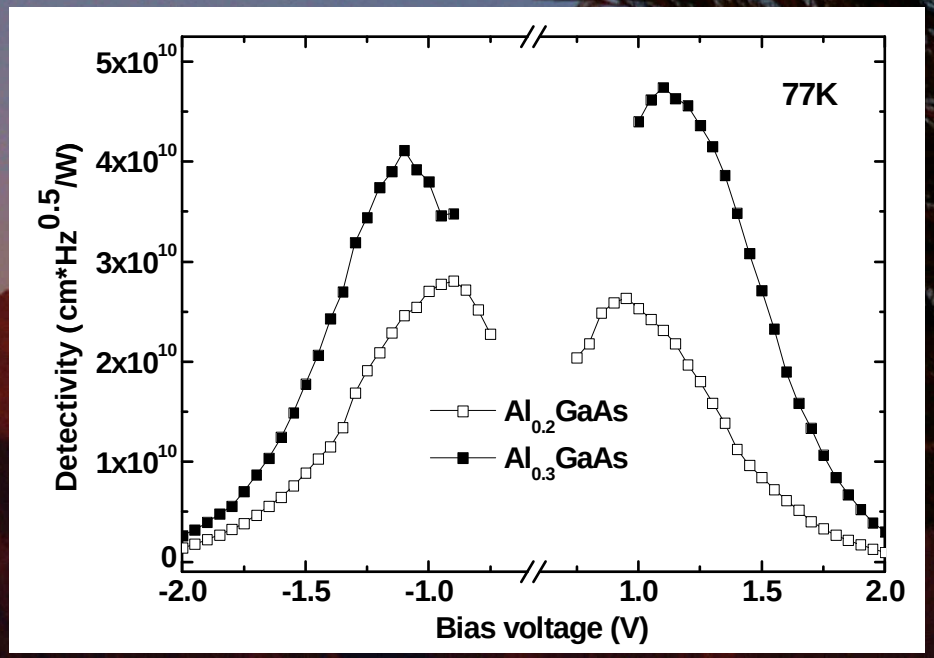
Intermixing effect



- Stronger intermixing with GaAs layers.
- InGaAs QDs are formed
- When Al content > 0.2 intermixing and confinement effects balanced

$Al_{0.2}Ga_{0.8}As$ v.s $Al_{0.3}Ga_{0.7}As$



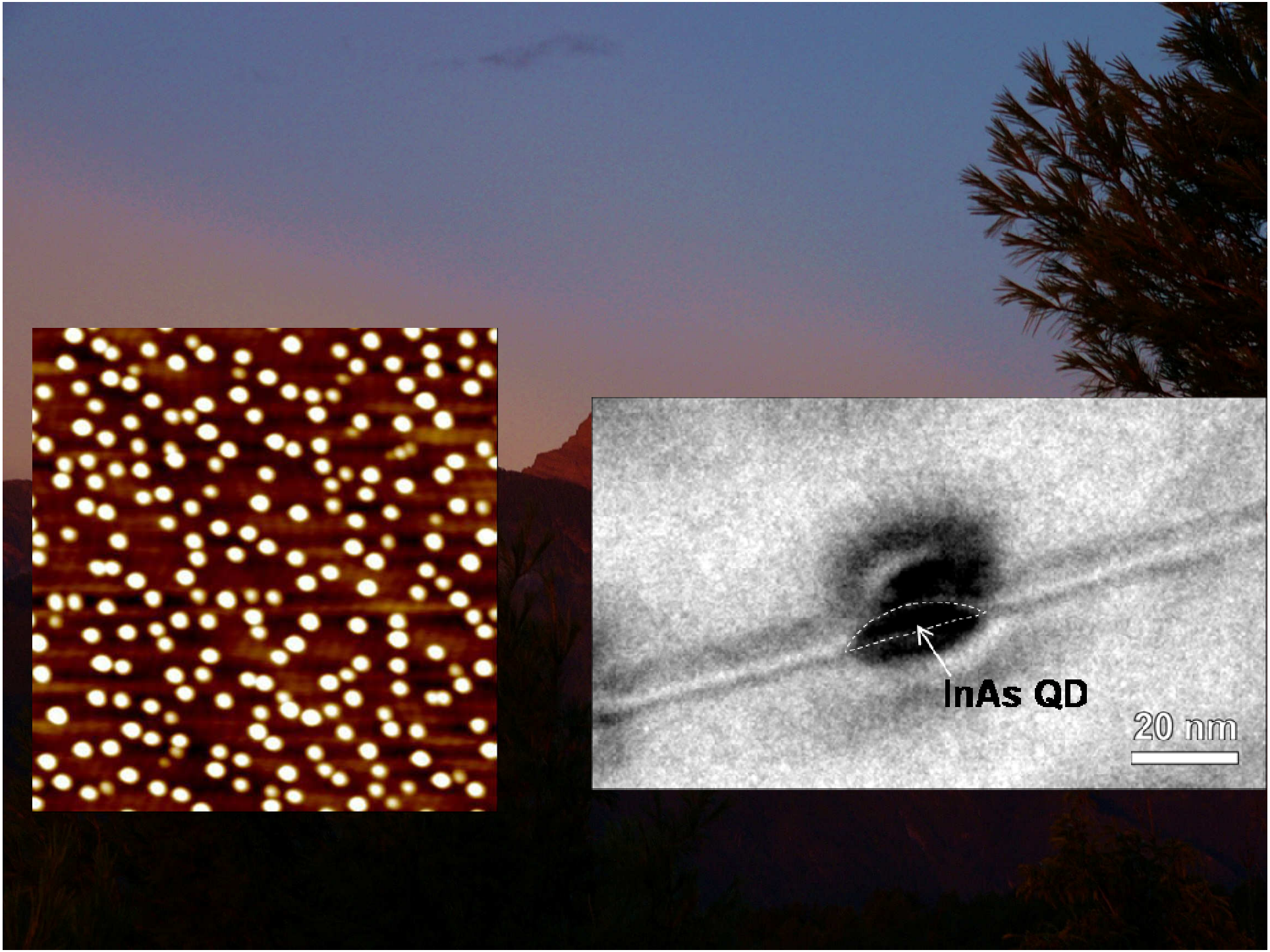


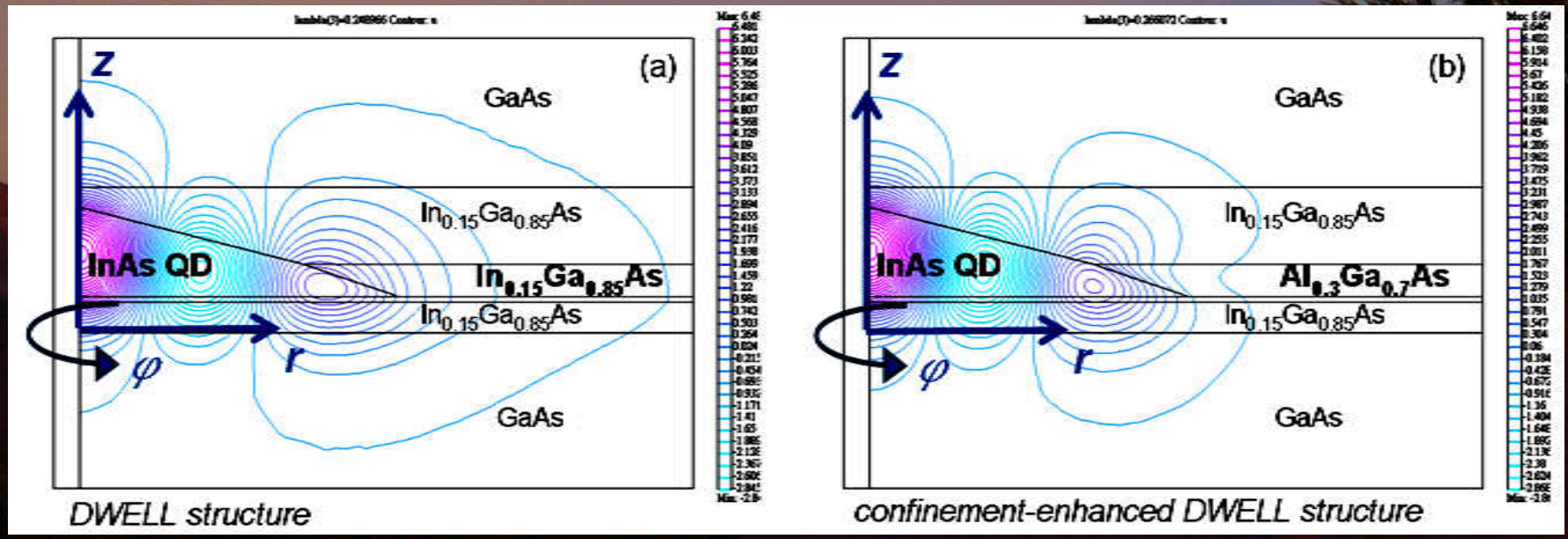
- Both gain and dark current are higher with $Al_{0.2}Ga_{0.8}As$ barriers
- Higher barrier still enhances the performance

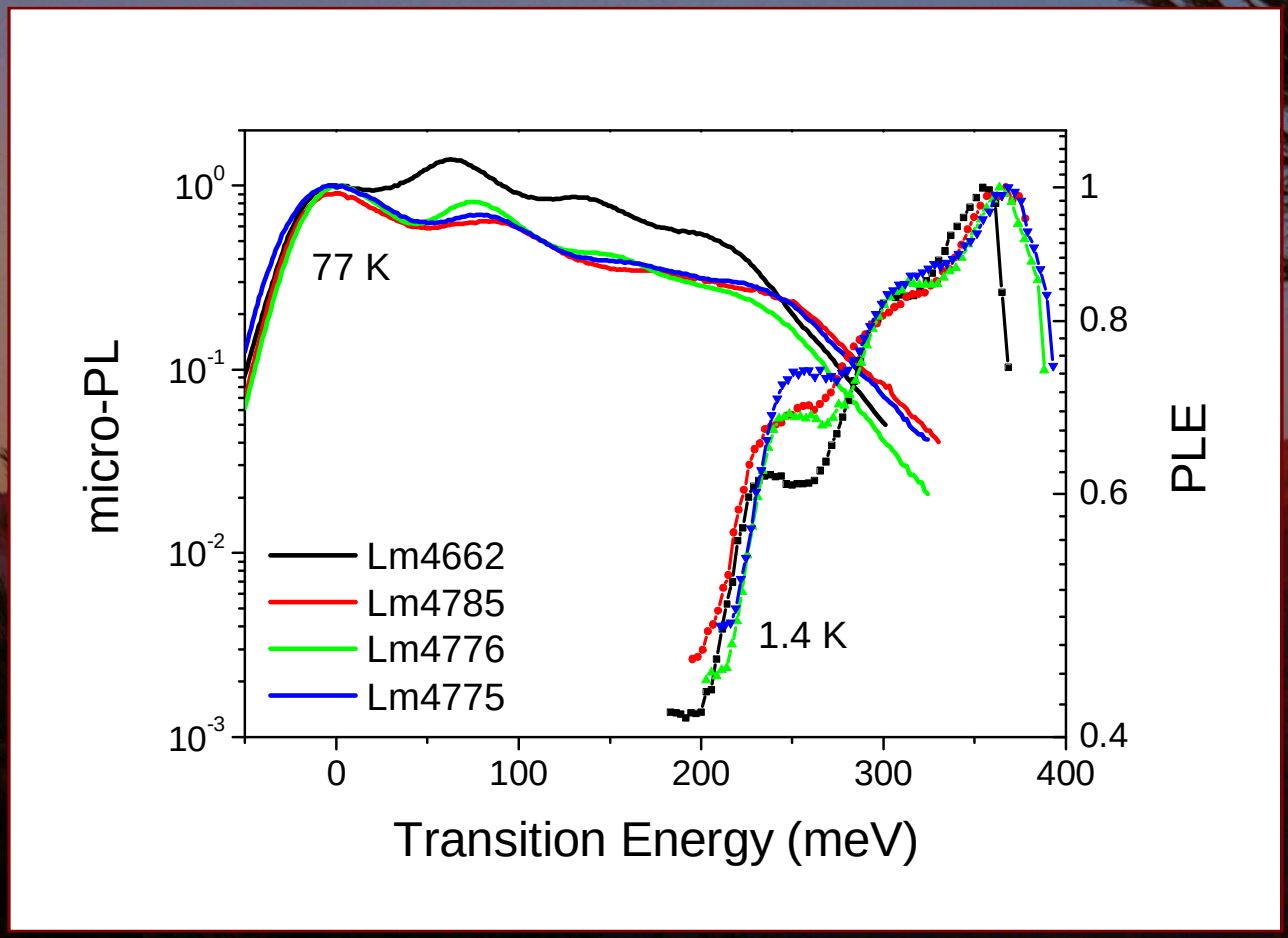
Summary

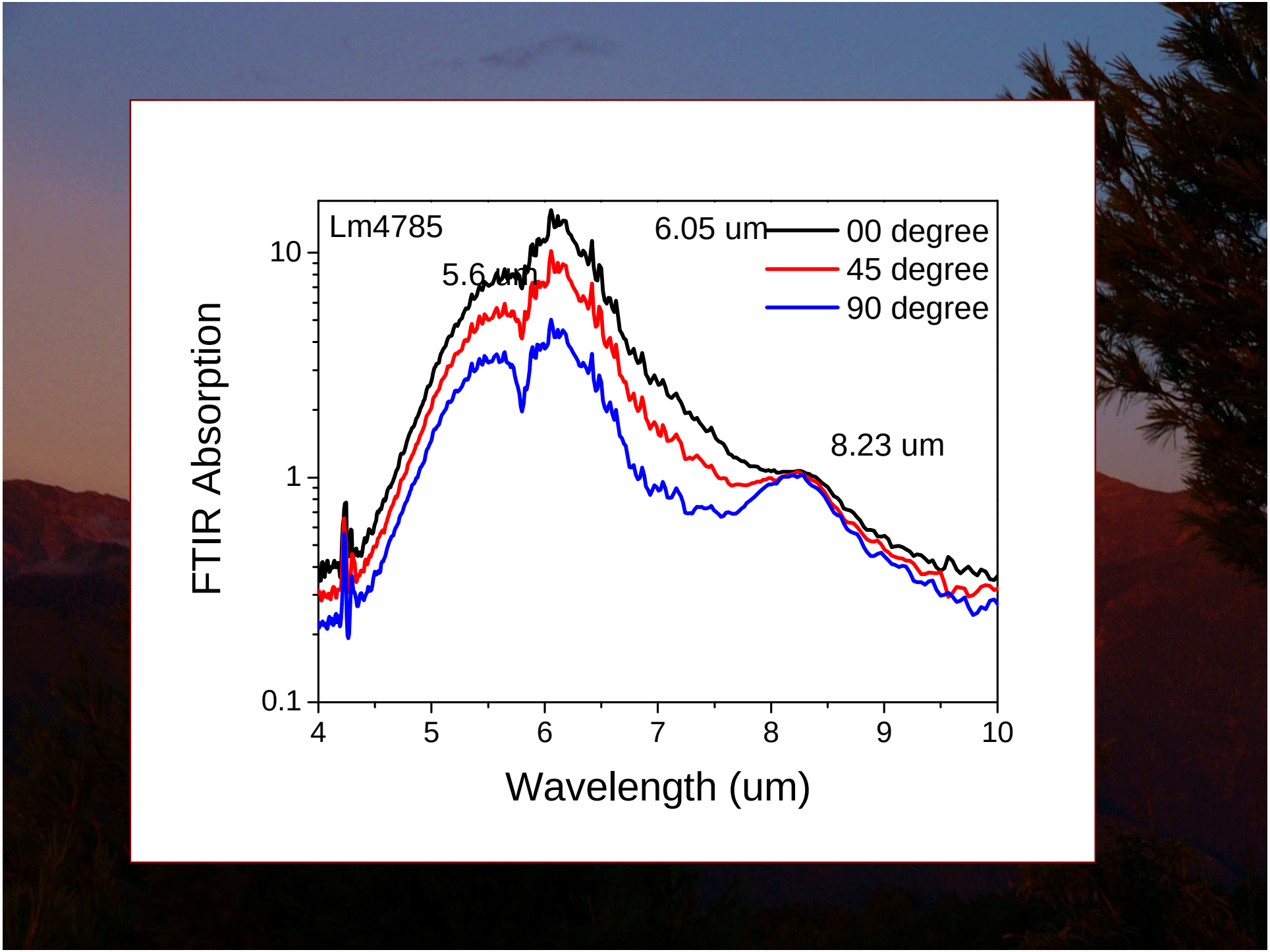
- Thin layer of high band gap material could generates dramatic changes for QDIPs
- The higher lateral confinement could enhance the QE especially the normal incident absorption.
- The parameters of the AlGaAs layer provide additional flexibilities
- Different structures are possible for different application requirements


Thank You!


InAs QD
20 nm


z
(a)
GaAs
$In_{0.15}Ga_{0.85}As$
InAs QD
$In_{0.15}Ga_{0.85}As$
$In_{0.15}Ga_{0.85}As$
φ
r
GaAs
DWELL structure
z
(b)
GaAs
$In_{0.15}Ga_{0.85}As$
InAs QD
$Al_{0.3}Ga_{0.7}As$
$In_{0.15}Ga_{0.85}As$
φ
r
GaAs
confinement-enhanced DWELL structure


micro-PL
PLE
77 K
1.4 K
Lm4662
Lm4785
Lm4776
Lm4775
Transition Energy (meV)
10^0
10^{-1}
10^{-2}
10^{-3}
1
0.8
0.6
0.4
0
100
200
300
400


Lm4785
6.05 um
5.6 um
8.23 um
00 degree
45 degree
90 degree
FTIR Absorption
Wavelength (um)
10
1
0.1
4
5
6
7
8
9
10